ミナミマグロ 1 歳魚の曳縄指数
– ピストンライン指数とグリッドタイプ曳縄指数の更新 –

Trolling indices for age-1 southern Bluefin tuna: update of the piston line index and the grid type trolling index

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要約

オーストラリア南西岸にて、2006 年から 2014 年、2016 から 2019 年に行われた曳縄調査および 1996 年から 2006 年に行われた音響調査の曳縄漁獲データから、ミナミマグロ 1 歳魚の 2 種類の資源量指数を求めた。一つは従来から報告しているピストンライン指数（TRP）である。もう一つは 2014 年に開発したグリッドベースの曳縄指数（TRG）で、両調査の全曳縄操業データを利用した、緯経度 0.1 度、日付、時間、海域別のグリッドにおける曳縄探索距離当たりのミナミマグロ 1 歳魚の群数である。探索合計距離約 55,506 km、ミナミマグロ 1 歳魚群数合計 904 群から求めたデータは、ゼロキャッチが多かったことから GLM のデルタログノーマルによる標準化をした。22 年間の TRG は、オペレーティングモデルで推定した加入量、および日本延縄 4 歳魚と 5 歳魚の CPUE とトレンドがよく一致していた。TRP と TRG は CCSBT における資源評価に貢献できるものと考えられる。

Summary

Two recruitment indices of age-1 southern bluefin tuna *Thunnus maccoyii* was developed using trolling catch data in two surveys in the southwestern coast of Australia, the acoustic survey from 1996 to 2006 and the trolling survey from 2006 to 2014, and from 2016 to 2019. One index is the piston-line trolling index (TRP) which have been reported to CCSBT. The other is the grid-type trolling index (TRG) which was developed in 2014. TRG utilizes all of the trolling data that aggregated the trolling effort and the number of southern bluefin tuna schools caught by date, hour, area type, and 0.1 degrees square in latitude and longitude. Dataset included about 55,506 km total distance searched with 904 schools. GLM of the delta-lognormal method was applied for CPUE standardization because of a high percentage of zero catch data. Medium term trends of TRG in 22 years were agreed to those of recruitment

estimates from the operating model and both age-4 CPUE and age-5 CPUE from Japanese longline. Trends of TRG and TRP were similar to each other. TRG and TRP are expected to contribute to the CCBST stock assessment.

Introduction

Trolling survey for southern bluefin tuna (*Thunnus maccoyii*: SBT) aims to provide a recruitment index of the stock at age-1. The survey has been carried out in the southern coast of Western Australia from 2006 to 2019, except 2015. It has provided an index named the piston-line trolling index (TRP[1]) which have been reported to CCSBT (Itoh and Kurota 2006, Itoh 2007, Itoh and Sakai 2007, 2008, 2009, 2010, Itoh et al. 2011, 2012a, 2013, Itoh and Tokuda 2014, Itoh and Tsuda 2016, 2017, 2018). In addition, trolling survey operated trolling in other areas of the piston line. The large area was also surveyed with trolling operation in the acoustic survey between 1996 and 2006. Using these data, a standardization of the trolling survey index (TRG) was developed in 2014 (Itoh and Takahashi 2014). The updated TRP and TRG are provided in this paper.

Materials and methods

1. Piston-line Trolling Index　TRP

Trolling catch data on the piston-line in the acoustic survey in 2005 and 2006 and in the trolling survey between 2006 and 2014, and from 2016 to 2019, were used for analysis. Details of the survey were described in other papers that submitted every year (e.g. Itoh et al. 2013, 2016, Tsuda and Itoh 2017, 2018, 2019). It contains data in a total of 199 times on the piston-line (Table 1). Data of another ten times were not included because the line was incomplete due to mainly rough sea conditions. Datasets were separated between the acoustic survey and trolling survey because there were differences in the two surveys, such as survey design, a vessel used especially in size and specification of trolling gears. Trolling operations on the piston-line were repeated from 8 to 20 times per year.

The piston-line was set off Bremer Bay, in the middle of the whole area for acoustic and

[1] TRP and TRG are previously called the piston-line trolling index (PTI) and the grid-type trolling index (GTI), respectively. New designations of TRP and TRG are used to avoid confusion with gene tagging (GT) in CCSBT.

trolling surveys (Fig. 1). The exact locations have been changed a few times since its first determination in 2005 (Fig. 2). In 2006, the piston-line was moved eastward to avoid the array of a hydrophone for acoustic tags deployed in the acoustic tagging research project on SBT (Fujioka et al. 2010). In 2007, the offshore part of the piston line, which had caught a small number of fish over the past few years, was cut and extended towards the coast. The small vessels used for the trolling survey allowed operation in the closer area to the coast, while the large vessel used for the acoustic survey lasted up to 2006 could not. In 2008, the piston-line was moved west in order to avoid the array of a hydrophone for acoustic tags and to bring closer to the bay the vessel spent at night. The locations of the piston-line have been almost the same since 2008 to 2019.

The piston-line in 2005 and 2006 had a larger part of offshore than after 2007. We made an adjustment that the distance of the piston-line in offshore is the same as that in 2007 and removed some effort data in 2005 and 2006. There was no SBT catch that removed by this adjustment. No correction was made on the coastal portion of the 2005 and 2006 piston-line.

The summary of data after the correction was made for the location of the offshore point of the piston-line, as well as several records on time as shown in Table 2. It reached a total of 487.9 hours in search time and 6,288 km in search distance. The number of SBT caught was 745 individuals.

Piston line trolling index (TRP) was calculated as a catch of age-1 SBT per 100 km search distance. There were five types of catch definition and TRPs were calculated for each of them.

(1) School of age-1 SBT. A catch of age-1 SBT that apart from 2 km in distance from last catch of age-1 SBT is defined as a different school. TRP from this definition is “TRI_2km.”

(2) School of age-1 SBT. A catch of age-1 SBT that apart from 20 minutes in time from last catch of age-1 SBT is defined as a different school. TRP from this definition is “TRI_20min.”

(3) School of age-1 SBT. A catch of age-1 SBT that apart from 30 minutes in time from last catch of age-1 SBT is defined as a different school. TRP from this definition is “TRI_30min.”

(4) Number of times age-1 SBT caught. All the catches even it was likely to be from the same school were counted as different. TRP from this definition is “TRI_Times.

(5) Number of age-1 SBT individuals. TRP from this definition is “TRI_ind.”

Confidence intervals of TRP were calculated from data sampled 1000 times by bootstrap method, and the results were shown by box plots or median, 5% and 95% points.

Usually, piston-line was surveyed two times per day. It was evaluated whether the two

datasets of the same day, outward run and inward run, can be assumed to be independent. If two datasets on the same date were strongly correlated, the variance between them would be small. To examine this possibility, we limit the data in a year for both outward and inward runs were operated on the same day. We chose data randomly with 1000 times bootstrap in following two cases and compared the variability of estimates. One case was that for example, it was three days, chose three days randomly and used data in both outward and inward runs of these days to calculate TRP. Another case was that chose six days randomly and used data either outward or inward run (it also chose randomly) to calculate TRP.

2. Grid-type Trolling Index　TRG

Data came from trolling catch in the acoustic survey between 1996 and 2003, 2005 and 2006, and the trolling survey between 2006 and 2014, and from 2016 and 2019. The surveys were carried out in the period from December to March, and the year was represented in the year of January in this paper.

Search distance of trolling, catch of age-1 SBT and CPUE (catch/100km searched) were aggregated by survey type (acoustic survey / trolling survey), year, month, day, hour, longitude (0.1 degree), latitude (0.1 degree) and five area types (described later). Data west of 117.5E were removed.

Time intervals of a recording of latitude and longitude differed by year. Up to 2005, latitude and longitude were only recorded when any events occurred, including hourly environmental observation, catch, detection of anything in sonar, the arrival of transect reflection point, CTD observation, etc. Then, locations at every one minute were calculated by interpolating two points available. Since 2006, locations were recorded in short interval such as 10 or 15 seconds by GPS logger devises and mean locations by one minute were used for analysis.

In the acoustic survey, it was planned that trolling was operated in the daytime from 6 AM to 6 PM. Actual times of start and end of trolling were not recorded. Some records of catch before 6 AM and after 6 PM were removed. In the trolling survey, all the times of start and end of trolling operations were recorded.

Catch was limited for age-1 SBT (40-63 cmFL) in the analysis. Catch was defined as a fish school and schools were defined as that successive catches more than 30 minutes were from different schools.

In the research area, SBT distribution was distinctly different by area type which categorized as follows (Fig. 1).

Lump: Small seamounts or small islands. Its center position was measured on nautical

charts. A range of effect of each of lumps was assumed by observing the contour of depth and SBT catch locations. Lumps specified for analysis were "BaldIs27", "lumpA40", "lumpB36", "lumpC35", "lumpD48", "lumpE5", "lumpF50", "lumpG35", "lumpH49", "BBeast50", "BBeast16", "Investigator Island", "West Group (Figure of Eight) ". The figures came from the depth of its summit.

Maude Reef: A large lump off Albany. It was treated separately because it was very large in size and surveyed in many years.

Shelf edge: A range near 200 m isobath. The range was determined from observing SBT catch records that 3.0 km toward inshore and 0.5 km toward offshore. Two People Canyon off Albany, a large sea canyon, was included in shelf edge.

Onshelf: northern area of the shelf edge.

Offshore: the southern area of the shelf edge.

Delta model was applied for CPUE standardization because of a high percentage of zero observations (Lo et al. 1992, Li and Jiao 2013). The delta model handles zero data and positive catch data in two separate sub-models, i.e. one sub-model to estimate the probability of catching SBT age-1 (probability sub-model) with an assumption of binomial distribution and logit link function, and the other to fit the positive catch data (positive catch sub-model) with an assumption of lognormal distribution.

Probability sub-model:

log(p/(1-p)) ~ year + month + hour + area + + survey + offset(log(distance)) + error

error ~ binomial

where p is the probability of positive catch.

Positive catch sub-model:

log(catch) ~ year + month + hour + area + survey + offset(log(distance)) + error

error ~ gaussian

In this GLM standardization, the explanatory variables were selected based on the AIC using MuMIn package in R software v3.6.0 (R-core team 2012). The MuMIn package calculates the AIC for models of all combinations of the explanatory variables. The lowest AIC model containing the year explanatory variable was selected as the best model. Product of estimates from these two sub-models gives the final estimate of the Grid-type Trolling Index (TRG).

The program codes were corrected from the previous one in a few points, including for the standardization model and least square mean (LS-mean) calculation. The bootstrap method was applied to obtain a range of the estimate. 1000 datasets were made through stratified sampling by year.

TRG was compared to various indices: the aerial survey index, recruitment estimated from the 2017 stock assessment based on the reference set operating model (OM) and age-4 and age-5 all vessel CPUE of Japanese longline.

R software (version 3.6.0) was used for analysis (R-core team 2012).

Results

1. Piston-line Trolling Index: TRP

Figure 3 and Table 3 show the five types of estimated TRP by different school/catch definition. Figure 4 shows the median of the five types of indices that adjusted to the mean of each. Since no age-1 SBT in 2019 trolling survey was caught on the piston line (CCSBT/1909/25), Trolling Index of Piston-line (TRP) in 2019 became zero. The small differences were observed among the five type indices between 2006 and 2010 and there was a large difference between school indices (TRI_20min, 30min and 2km) and catch indices (TRI_times and ind.) in 2013. The relative index of TRI_30min was consistent with the index from the acoustic survey in 2006. The fluctuation in TRI_30min overtime was smaller among the five types of indices. Therefore, the TRI_30min index was submitted to CCSBT data exchange as trolling index of piston-line.

2. Grid-type Trolling Index: TRG

Summary of data aggregated by grid is shown in Table 4. It consists of 10,749 records in total that reach about 55,506 km search distance and 904 age-1 schools. One record with anomalously high CPUE (>2000) with a short distance was removed for analysis. Quite a large part of data was zero catch (91.6%).

Distributions of effort, catch and CPUE are shown by year (Fig. 5). It is noted that substantial efforts were made in areas other than the piston-line except 2007. It is also noted that few catches were observed in offshore area despite a substantial amount of efforts had been made (Table 5).

Nominal CPUE is shown in Fig. 6. Note that a substantial part of the effort was made up offshore where few SBT caught from 1996 to 2005. It must be underestimated in this period

compared to the latter half period.

The selected GLM models based on the AIC were follows:

Probability sub-model:

log(p/(1-p)) ~ year + month + hour + area + offset(log(distance)) + error

Positive catch sub-model:

log(catch) ~ year + area + offset(log(distance)) + error

Relationship between the probability of catch and various variables and between positive catch and various variables are shown in Fig.7 and 8, respectively. The estimated values are shown in Table 7 and Table 8. QQ plot of positive catch sub-model is shown in Fig. 9. LS-means for year trend in each sub-model are shown in Table 9 and 10. Year trend of the probability sub-model was transformed with logit function and that of the positive catch sub-model was transformed with an exponential function. Indices of both sub-models and point estimation of standardized Grid-type Trolling Index (TRG) are shown in Table 11 and Fig. 10.

Table 12 and Figure 11 show standardized TRG with confidence interval calculated through 1000 times bootstrap. TRG showed considerable low levels in 2000-2003, then increase in 2005-2008 and relatively high level in 2006-2016 with large fluctuation from year to year. TRG values in recent three years (2017-2019) have returned to relatively low levels, similar to those in 2003 and 2005, although not at the lowest level,

3. Comparison to other indices

Aerial survey

Figure 12 shows comparison between aerial survey index and TRG. Aerial survey index is a mix of age-2, age-3 and age-4. In the figure, age-3 was assumed to assign a year class of the aerial survey index. The trends of both TRG and the aerial survey index were not similar to each other over time. Note that the aerial survey index was not obtained around 2000YC when extremely low recruitment observed. The high value in 2013YC in the aerial survey was not supported by the TRG.

OM recruitment

Figure 13 shows comparison between recruitment estimated from the 2017 stock assessment based on the reference set operating model (OM) and TRG by year class (YC). The general trend of TRG is similar to that of OM recruitment. Historical low levels of OM recruitment in 1999-2001 are captured by TRG and TRG has been relatively high levels after

2005YC as same as in OM's. The high value in 2013YC in OM recruitment was attributed from the extremely high value in the aerial survey index in 2016. This high value was not corresponded with the TRG. TRG captured increase/decrease change in OM recruitment (e.g. 2004-2005YC, 2008-2011YC and 2016-2018YC) well while failed in a few years (e.g. 1998YC, 2007YC). TRG in the most recent 3 years (2016-2018YC) has been much lower than those average in 2010-2013YC.

Age-4 and age-5 all vessel CPUE of Japanese longline

Figure 14 and Figure 15 show comparisons between age-4 and age-5 all vessel CPUE of Japanese longline and TRG. The low level of TRG in 1999-2001YC and the high level in 2005-2013YC were supported by both CPUEs. CPUE values in both age-4 and age-5 are not yet available for the most recent four years of TRG values.

4. Discussion

The present paper provided updated Piston-line trolling index (TRP) and Grid-type trolling index (TRG) of SBT recruitment indices. Both trolling indices are based on catch that is the number of schools. When we encountered SBT school in the survey, the numbers of fish individuals caught and catch times could have increased if we handled the trolling line well and/or the vessel moved well to catch up or attract the school. The numbers of fish individuals caught and catch times were decreased when a suspended fishing operation such as several trolling lines was tangled at one catch and we needed some time to solve the tangling. The numbers of fish individuals or catch time were affected such crew skills of trolling. The number of schools was selected as a catch to avoid the influence of crew skill. However, the definition of catch as a school for index means to set an assumption that the probability distribution of the size of school (the number of individuals per school) is the same every year.

There were various types of school definition. We explored three definitions; two subsequent catches are from different schools if 20 minutes apart, 30 minutes apart, and 2 km apart. Definition by time may be inappropriate because it is affected by crew skill on trolling gear and definition by distance seems more appropriate. Detail location data every 10 seconds have been available since 2006 by using GPS data logger. However, because detail location records were not available in the period from 1996 to 2005, the 30 minutes definition was chosen to keep the consistency. Fortunately, no large difference was observed among trends of the index in different catch definition.

TRP has a potential problem that it has an upper limit because the piston-line has a determined distance. At present, the trolling survey operates the piston-line with about 34 km

in 2 hours 36 minutes on average. When school definition is 30 minutes, six schools and TRP = 17.1 becomes an upper limit. If catches were repeated less than 30 minutes interval, it would result in the number of schools caught as 1 and TRP = 2.8, despite there have been many catches. However, up to now, TRP trends were similar among various types of catches, including 30 minutes, catch times and number of individuals, and suggests such an extreme situation did not occur.

TRP was nominal value indices that not standardized like as using GLM. It does not need standardization because the survey design itself was standardized that the vessel used, specification of trolling gears and survey methods have been identified for 14 years and the survey was carried out in the almost same area and season. TRP was separated so far that from the acoustic survey (TRP (acoustic)) and that from the trolling survey (TRP (troll)). In the GLM of TRG, the difference in the survey types was not significant. It may be appropriate to combine the two TRPs into one.

TRG is a comprehensive index that includes not only the piston-line but also all the area surveyed. TRG enabled to extend the years to as long as 21 years, by adding the trolling in the acoustic survey from 1996 to 2003. The acoustic survey and the trolling survey were not originally designed to obtain TRG. However, because the acoustic survey was well designed to cruise randomly in the research area for sonar detection, the trolling catch operated simultaneously in the daytime is expected to be a random sampling in the area. While the survey area was concentrated on the piston-line in 2006 and 2007, the trolling survey was also operated in the larger area since 2008 intending development of TRG. When trolling was operated on a lump, we tried to operate trolling also in the area out of the lump so that collect data to evaluate the SBT distribution difference in area types.

In GLM standardization, the delta method which frequently used for data with a high percentage of zero observation was used. Area type was highly significant in the probability sub-model. It is well known the effect of sea bottom topography, such as lumps, on SBT distribution (Hobday and Campbell 2009). It should fully consider the effect of lumps and islands on SBT distribution for survey design. Tsuda and Itoh (2017) showed weather conditions have a negligible effect on the standardization of TRG (CCSBT-ESC/1708/24). However, ocean environmental conditions might affect the distribution and residence time of SBT in the survey area. Therefore, it should consider incorporating environmental variables such as sea surface temperature and chlorophyll into the standardization of the model.

The trend of TRG year class (YC) was similar to those of recruitment from OM and age-4 and age-5 CPUEs of Japanese longline. The correlation was depending on broader scale agreement that medium level in year classes in the mid-1990s, low level in the 2000YC-

2002YC and high level since 2005YC. The trends of both TRG and the aerial survey index were not similar to each other over time. Especially the high recruitment in 2013YC from aerial survey index was not supported by TRG.

TRP and TRG in recent three years (2017, 2018 and 2019) indicate the low recruitment level in 2016YC, 2017YC and 2018YC. Now, we cannot verify those low recruitments because the recruitment information is limited. Therefore, it is necessary to carefully monitor the information such as estimation of age-2 abundance by gene tagging and CPUE of Japanese longline in the next few years.

Acknowledgment

We thank Mr. Colin and Mr. Bond of F/V The Southern Conquest and Mr. Totterdell in MIRG for their help of cruise. We thank AFMA given us scientific research permission in the Australian coastal waters (#1004076).

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Table 1. Number of times piston-line surveyed

Year	Total	Used for index	Incomplete and not used for index
Acoustic Survey			
2005	21	20	1
2006	22	18	4
Trolling Survey			
2006	16	12	4
2007	14	14	
2008	10	10	
2009	11	10	1
2010	11	11	
2011	12	12	
2012	14	14	
2013	13	13	
2014	14	14	
2016	14	14	
2017	10	10	
2018	9	9	
2019	8	8	
Total	199	189	10

Table 2. Summary data on piston-line survey

Acoustic survey

Year	Value	Search hours	Search distance (km)	Date	Start time	End time	sch20min	sch30min	sch2km	hit.times	number SBT	Index sch20min	Index sch30min	Index sch2km	Index hit.times	Index numbser SBT
2005	min	1:57	30.3	2005/1/15	5:45	8:10	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:26	30.3	2005/2/15	12:23	14:23	2	2	3	5	11	6.61	6.61	9.92	6.53	6.36
	mean	2:09	30.3	2005/1/30	8:38	10:47	0.70	0.60	0.80	1.00	2.00	2.31	1.98	2.64	3.31	6.61
	total	43:17	605.0				14	12	16	20	40					
2006	min	1:52	29.7	2006/1/15	6:11	8:14	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:50	29.7	2006/2/13	14:54	16:50	3	2	6	12	27	10.11	6.74	20.22	40.43	90.97
	mean	2:07	29.7	2006/1/27	10:13	12:21	1.61	1.39	2.50	4.33	7.89	5.43	4.68	8.42	4.60	6.58
	total	38:16	534.2				29	25	45	78	142					

Trolling survey

Year	Value	Search hours	Search distance (km)	Date	Start time	End time	sch20min	sch30min	sch2km	hit.times	number SBT	Index sch20min	Index sch30min	Index sch2km	Index hit.times	Index numbser SBT
2006	min	2:08	26.8	2006/1/23	5:15	7:30	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:47	29.8	2006/1/30	11:07	17:45	4	3	4	7	16	13.77	11.52	13.77	23.58	61.42
	mean	2:24	28.6	2006/1/26	8:26	11:59	1.42	1.25	1.58	3	6	4.98	4.41	5.59	9.66	21.54
	total	28:37	349.2				15	13	17	26	62					
2007	min	2:14	28.7	2007/1/22	6:46	9:46	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:15	36.1	2007/1/28	11:31	18:18	5	5.1.43	6	7	21	16.63	16.63	18.11	23.49	69.83
	mean	2:44	32.5	2007/1/25	8:53	13:41	1.93	20	2.36	3	7	6.13	4.55	7.51	9.84	22.53
	total	38:24	455.0				27		33	43	98					
2008	min	2:32	31.6	2008/1/21	6:55	9:53	1	1	1	1	1	2.81	2.81	2.81	2.81	2.89
	max	3:14	35.9	2008/1/31	14:26	18:05	3	3	3	3	7	8.61	8.61	8.61	8.89	19.72
	mean	2:47	34.6	2008/1/25	9:22	13:37	1.70	1.70	1.90	2.10	4.70	4.92	4.92	5.49	6.07	13.52
	total	27:50	346.4				17	17	19	21	47					
2009	min	2:16	30.7	2009/1/18	6:23	8:46	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:55	35.9	2009/1/28	12:06	17:04	3	3	3	5	114	9.76	9.76	9.76	14.59	32.11
	mean	2:41	34.3	2009/1/21	8:19	12:28	1.30	1.20	1.30	1.70	3.70	3.87	3.58	3.87	5.02	10.86
	total	26:52	343.2				13	12	13	17	37					
2010	min	2:27	33.7	2010/1/20	5:22	8:02	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:04	36.3	2010/1/31	13:32	16:06	2	2	3	8	11	5.93	5.93	8.69	23.72	31.85
	mean	2:40	34.7	2010/1/26	8:17	11:57	1.00	0.91	1.18	2.09	3.36	2.88	2.62	3.41	6.10	9.77
	total	29:22	381.5				11	10	13	23	37					
2011	min	2:20	27.6	2011/1/26	5:28	8:28	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:20	35.3	2011/2/8/	10:32	17:46	4	4	6	10	18	14.47	14.47	18.00	30.01	65.12
	mean	2:46	33.6	2001/1/31	7:41	12:22	2.08	1.67	2.25	3.08	5.92	6.33	5.11	6.77	9.37	18.52
	total	33:17	402.8				25	20	27	37	71					
2012	min	2:31	33.8	2012/1/25	5:21	5:21	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:27	36.2	2012/2/7	13:27	13:27	2	2	2	2	5	5.77	5.77	5.77	5.77	14.42
	mean	2:52	35.3	2012/1/31	7:50	7:50	0.57	0.57	0.64	0.64	0.93	1.63	1.63	1.83	1.83	2.66
	total	40:07	493.6				8	8	9	9	13					
2013	min	2:38	33.8	2013/1/19	5:56	5:56	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:21	36.0	2013/1/31	12:21	12:21	2	2	3	13	18	5.69	5.69	8.42	37.72	52.23
	mean	2:49	35.2	2013/1/24	8:34	8:34	1.54	1.31	1.69	3.62	7.38	4.34	3.70	4.78	10.26	20.95
	total	36:43	458.0				20	17	22	47	96					
2014	min	2:30	34.3	2014/1/26	6:04	8:55	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:04	35.7	2014/2/7	11:54	14:29	3	2	4	7	7	8.41	5.83	11.21	19.62	20.23
	mean	2:46	35.0	2014/1/31	1:53	5:23	1.14	1.00	1.36	1.71	2.36	3.26	2.86	3.88	4.88	6.74
	total	38:45	490.0				16	14	19	24	33					
2016	min	2:22	33.1	2016/1/27	5:40	8:09	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:53	35.2	2016/2/8	12:30	16:54	3	3	3	3	9	8.74	8.74	8.74	8.74	25.60
	mean	2:37	34.6	2016/2/2	8:14	11:40	1.50	1.36	1.57	1.71	3.57	4.33	3.92	4.54	4.95	10.26
	total	36:42	484.5				21	19	22	24	50					
2017	min	2:12	33.4	2017/1/31	6:22	9:12	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:35	37.0	2017/2/7	9:05	11:40	2	2	2	2	5	5.76	5.76	5.76	5.76	14.96
	mean	2:24	34.9	2017/2/2	3:48	7:08	0.60	0.60	0.60	0.60	1.90	1.71	1.71	1.71	1.71	5.44
	total	24:07	349.2				6	6	6	6	19					
2018	min	2:16	33.2	2018/2/4	6:15	9:16	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:35	35.4	2018/2/12	14:53	17:12	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	mean	2:23	34.6	2018/2/7	10:59	13:33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total	21:27	311.1				0	0	0	0	0					
2019	min	2:37	34.8	2019/2/3	5:55	8:40	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	4:10	36.2	2019/2/11	13:14	17:21	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	mean	3:00	35.5	2019/2/5	8:29	11:29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total	24:00	284.2				0	0	0	0	0					

A part of data not used for TRP has already excluded.

Table 3. Piston-line Trolling Index value

index	Survey	Year	Minimum	5%	Median	95%	Maximum
sch20min	Acoustic	2005	0.496	1.322	2.314	3.471	4.297
	Acoustic	2006	3.369	4.493	5.429	6.364	7.113
	Trolling	2006	1.994	3.380	4.841	6.562	8.552
	Trolling	2007	2.783	4.320	6.139	8.052	10.486
	Trolling	2008	2.860	3.980	4.918	5.898	6.893
	Trolling	2009	1.407	2.422	3.851	5.530	7.301
	Trolling	2010	1.044	1.858	2.881	3.923	4.713
	Trolling	2011	2.661	4.400	6.334	8.467	10.226
	Trolling	2012	0.202	0.816	1.625	2.448	3.298
	Trolling	2013	2.405	3.480	4.344	5.010	5.633
	Trolling	2014	1.226	2.242	3.257	4.260	5.452
		2015					
	Trolling	2016	1.653	2.915	4.337	5.625	7.026
	Trolling	2017	0.270	0.829	1.702	2.829	3.730
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
sch30min	Acoustic	2005	0.331	1.157	1.983	2.975	3.801
	Acoustic	2006	3.182	3.931	4.680	5.429	5.990
	Trolling	2006	2.007	3.111	4.278	5.422	6.388
	Trolling	2007	1.299	2.859	4.434	6.624	9.066
	Trolling	2008	3.130	4.013	4.917	5.900	6.665
	Trolling	2009	1.408	2.271	3.559	5.125	6.240
	Trolling	2010	0.787	1.587	2.612	3.466	4.409
	Trolling	2011	2.668	3.444	5.088	7.019	8.749
	Trolling	2012	0.397	0.815	1.622	2.429	2.872
	Trolling	2013	2.364	2.835	3.703	4.370	5.007
	Trolling	2014	1.220	2.051	2.863	3.683	4.493
		2015					
	Trolling	2016	1.430	2.536	3.936	5.245	6.624
	Trolling	2017	0.000	0.836	1.705	2.614	3.727
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
sch2km	Acoustic	2005	0.331	1.322	2.644	3.967	5.289
	Acoustic	2006	5.054	6.364	8.236	10.670	13.478
	Trolling	2006	2.258	3.418	5.130	6.977	8.554
	Trolling	2007	3.252	5.151	7.438	10.010	12.207
	Trolling	2008	3.205	4.533	5.499	6.464	7.416
	Trolling	2009	1.136	2.333	3.848	5.486	7.415
	Trolling	2010	1.068	2.111	3.415	4.770	6.299
	Trolling	2011	3.107	4.578	6.761	9.146	12.101
	Trolling	2012	0.397	0.998	1.822	2.820	3.682
	Trolling	2013	2.392	3.696	4.773	5.845	6.704
	Trolling	2014	1.627	2.467	3.840	5.274	6.689
		2015					
	Trolling	2016	1.865	3.084	4.543	5.970	7.005
	Trolling	2017	0.279	0.836	1.702	2.829	3.485
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
hit.times	Acoustic	2005	0.331	1.653	3.306	5.124	7.107
	Acoustic	2006	7.488	9.921	14.414	19.468	25.083
	Trolling	2006	3.108	5.921	9.881	13.977	19.143
	Trolling	2007	3.063	6.389	9.570	13.416	17.369
	Trolling	2008	3.694	4.834	6.072	7.303	8.129
	Trolling	2009	1.165	2.806	4.923	7.525	10.268
	Trolling	2010	1.285	2.913	5.887	9.644	16.670
	Trolling	2011	3.852	5.663	9.361	13.445	20.655
	Trolling	2012	0.202	1.012	1.826	2.838	3.673
	Trolling	2013	4.324	6.302	9.944	15.108	20.039
	Trolling	2014	1.427	2.876	4.701	7.269	9.705
		2015					
	Trolling	2016	1.660	3.333	4.944	6.554	7.812
	Trolling	2017	0.270	0.827	1.702	2.838	3.738
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
number SBT	Acoustic	2005	0.661	3.140	6.446	10.578	15.371
	Acoustic	2006	12.355	18.157	26.394	35.753	52.039
	Trolling	2006	5.244	11.229	19.130	27.656	36.582
	Trolling	2007	9.262	14.724	22.597	31.452	45.399
	Trolling	2008	6.847	10.212	13.633	16.266	17.869
	Trolling	2009	1.451	5.693	10.562	16.280	22.297
	Trolling	2010	2.082	5.442	9.658	14.759	18.829
	Trolling	2011	5.046	9.043	18.174	28.688	38.160
	Trolling	2012	0.402	1.201	2.661	4.563	6.987
	Trolling	2013	8.219	14.533	20.929	27.232	35.221
	Trolling	2014	2.052	4.088	6.600	9.602	12.823
		2015					
	Trolling	2016	3.310	6.536	10.115	14.118	18.222
	Trolling	2017	0.000	2.544	5.445	8.720	12.378
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000

Table 4. Summary of data for Grid-type Trolling Index (TRG)

Survey	Year	N_Record	Time_Min	Time_Max	Range			
					South	North	West	East
Acoustic	1996	320	21 Jan. 1996 07:00	13 Feb. 1996 13:00	-35.2	-34.4	118.2	121.7
	1997	477	26 Jan. 1997 09:00	26 Feb. 1997 12:00	-35.3	-34.0	117.5	121.8
	1998	485	19 Jan. 1998 06:00	24 Feb. 1998 17:00	-35.4	-34.4	117.7	121.8
	1999	628	21 Jan. 1999 06:00	14 Mar. 1999 17:00	-35.4	-34.0	118.0	121.8
	2000	637	19 Jan. 2000 06:00	14 Mar. 2000 15:00	-35.4	-34.0	117.5	122.5
	2001	706	22 Jan. 2001 07:00	14 Mar. 2001 17:00	-35.4	-33.9	117.5	121.9
	2002	584	22 Jan. 2002 06:00	14 Mar. 2002 15:00	-35.4	-33.9	117.5	121.9
	2003	494	25 Dec. 2002 08:00	28 Jan. 2003 15:00	-35.3	-33.9	117.9	121.9
	2005	857	14 Jan. 2005 06:00	04 Mar. 2005 16:00	-35.3	-33.9	117.5	121.9
	2006	882	12 Jan. 2006 06:00	18 Feb. 2006 13:00	-35.4	-34.0	117.5	121.9
Trolling	2006	199	22 Jan. 2006 08:00	31 Jan. 2006 15:00	-34.8	-34.1	119.3	121.3
	2007	210	21 Jan. 2007 10:00	29 Jan. 2007 07:00	-34.8	-34.1	119.3	121.3
	2008	343	03 Dec. 2007 10:00	01 Feb. 2008 08:00	-35.5	-34.1	117.5	121.3
	2009	387	17 Jan. 2009 09:00	29 Jan. 2009 07:00	-35.5	-34.1	117.7	121.3
	2010	406	19 Jan. 2010 08:00	04 Feb. 2010 17:00	-35.5	-34.1	117.7	123.4
	2011	396	25 Jan. 2011 08:00	11 Feb. 2011 10:00	-35.5	-34.1	117.8	121.8
	2012	380	24 Jan. 2012 08:00	10 Feb. 2012 11:00	-35.5	-34.0	117.9	121.9
	2013	414	19 Jan. 2013 05:00	04 Feb. 2013 12:00	-35.5	-33.9	117.9	122.1
	2014	410	25 Jan. 2014 08:00	11 Feb. 2014 10:00	-35.4	-34.0	117.6	123.2
	2016	393	26 Jan. 2016 08:00	12 Feb. 2016 12:00	-35.5	-34.0	117.7	122.3
	2017	357	27 Jan. 2017 06:00	13 Feb. 2017 11:00	-34.9	-33.9	118.8	122.4
	2018	418	31 Jan. 2018 06:00	17 Feb. 2018 11:00	-34.9	-33.9	118.8	122.3
	2019	366	31 Jan. 2019 07:00	18 Feb. 2019 12:00	-35.5	-34.0	117.7	122.5

Survey	Year	Distance searched						SBT Catch
		Total	Offshore	Shelfedge	On Shore	Lump	Mauda Reef	
Acoustic	1996	2,786	1,107	383	906			21
	1997	3,206	1,289	416	1,340		6	38
	1998	3,255	1,377	339	1,400			34
	1999	3,979	1,769	343	1,733	1		56
	2000	4,048	1,620	289	1,756	128	4	17
	2001	4,388	1,546	385	2,066	230		20
	2002	4,287	1,354	429	1,587	216		9
	2003	2,363	638	326	1,675	111	10	29
	2005	5,051	1,162	408	3,155	220		62
	2006	3,882	1,230	383	2,293	42		84
Trolling	2006	911	130	182	569	29		27
	2007	903	59	215	623	6		33
	2008	1,171	139	114	860	30	28	44
	2009	1,425	115	227	981	29	73	41
	2010	1,531	163	202	1,018	41	108	56
	2011	1,428	144	194	996	54	39	58
	2012	1,429	135	168	907	116	103	38
	2013	1,554	141	164	1,107	37	104	50
	2014	1,631	93	157	1,245	79	57	50
	2016	1,540	164	187	1,109	47	32	68
	2017	1,499	87	78	1,238	95		27
	2018	1,763	285	84	1,353	41		26
	2019	1,477	115	79	1,117	94	72	16
Total		55,506	14,866	5,752	31,034	1,644	637	904

SBT Catch is the number of school with the definition of 30 minutes is necessary to be a different school from last catch.

Table 5. Summary of data by area type

Area	N_records	Catch	CPUE		
	All	positive catch	% positive	Mean	SD
Lump	402	80	19.4%	32.2	26.3
Maude Reef	181	48	26.0%	40.8	99.3
On shore	5,926	636	10.6%	22.9	24.5
Shelf edge	1,611	104	6.4%	41.3	56.3
Off shore	2,629	36	1.3%	38.7	58.5
Total	10,749	904	8.4%		

Table 6. AIC for two sub-models

	model	Log-Likelihood	AIC
probability sub-model	full	-2583.369	5248.7
	AIC selected	-2583.584	5247.2
positive catch sub-model	full	-868.854	1821.7
	AIC selected	-876.966	1807.9

Table 7. Estimated value by GLM for probability sub-model

	Estimate	Std. Error	z value	Pr (>| z |)	Significance
(Intercept)	-2.21993	0.31551	-7.03592	0.00.E+00	***
fyear1997	0.25815	0.29629	0.87127	3.84.E-01	
fyear1998	0.18755	0.29928	0.62667	5.31.E-01	
fyear1999	0.72057	0.28289	2.54719	1.09.E-02	*
fyear2000	-0.86637	0.34557	-2.50708	1.22.E-02	*
fyear2001	-0.85119	0.33669	-2.52812	1.15.E-02	*
fyear2002	-1.56842	0.41841	-3.74850	1.78.E-04	***
fyear2003	-0.41082	0.32555	-1.26193	2.07.E-01	
fyear2005	-0.06195	0.27384	-0.22624	8.21.E-01	
fyear2006	0.73546	0.25972	2.83172	4.63.E-03	***
fyear2007	1.08378	0.31764	3.41200	6.45.E-04	***
fyear2008	0.99877	0.30052	3.32345	8.89.E-04	***
fyear2009	0.56237	0.30582	1.83892	6.59.E-02	
fyear2010	0.80207	0.28944	2.77109	5.59.E-03	**
fyear2011	0.99313	0.28200	3.52170	4.29.E-04	***
fyear2012	0.35617	0.30033	1.18590	2.36.E-01	
fyear2013	0.68012	0.29077	2.33903	1.93.E-02	*
fyear2014	0.60444	0.28594	2.11385	3.45.E-02	*
fyear2016	1.16860	0.27762	4.20936	2.56.E-05	***
fyear2017	-0.02941	0.31787	-0.09252	9.26.E-01	
fyear2018	-0.06071	0.31913	-0.19023	8.49.E-01	
fyear2019	-0.71964	0.36083	-1.99442	4.61.E-02	*
fmonth2	0.02217	0.09170	0.24171	8.09.E-01	
fmonth3	-0.76277	0.25866	-2.94894	3.19.E-03	***
fmonth12	0.28637	0.32854	0.87165	3.83.E-01	
fhour7	-0.27539	0.16915	-1.62805	1.04.E-01	
fhour8	-0.36500	0.17333	-2.10586	3.52.E-02	*
fhour9	-0.42310	0.17628	-2.40016	1.64.E-02	*
fhour10	-0.43182	0.17717	-2.43728	1.48.E-02	*
fhour11	-0.60884	0.18178	-3.34936	8.10.E-04	***
fhour12	-0.45861	0.17651	-2.59828	9.37.E-03	**
fhour13	-0.56155	0.18189	-3.08723	2.02.E-03	***
fhour14	-0.23137	0.17360	-1.33276	1.83.E-01	
fhour15	-0.42697	0.18698	-2.28345	2.24.E-02	*
fhour16	-0.47000	0.20118	-2.33626	1.95.E-02	*
fhour17	-0.87486	0.25337	-3.45293	5.55.E-04	***
fareaMaudaReef	-0.24513	0.23539	-1.04140	2.98.E-01	
fareaOffshore	-3.51540	0.22836	-15.39444	0.00.E+00	***
fareaOnShore	-1.38861	0.14841	-9.35676	0.00.E+00	***
fareaShelfedge	-1.58894	0.17786	-8.93371	0.00.E+00	***

Significances are *** < 0.001, ** < 0.01 and * < 0.05.

Table 8. Estimate values by GLM for positive catch sub-model

	Estimate	Std. Error	t value	Pr (>| t |)	Significance
(Intercept)	-0.37262	0.16812	-2.21631	2.69.E-02	*
fyear1997	-0.18980	0.18191	-1.04341	2.97.E-01	
fyear1998	-0.09740	0.18349	-0.53084	5.96.E-01	
fyear1999	0.06270	0.16898	0.37107	7.11.E-01	
fyear2000	0.10912	0.21916	0.49790	6.19.E-01	
fyear2001	-0.41268	0.21005	-1.96471	4.98.E-02	*
fyear2002	0.04638	0.26647	0.17405	8.62.E-01	
fyear2003	0.17538	0.19295	0.90894	3.64.E-01	
fyear2005	0.02161	0.16802	0.12863	8.98.E-01	
fyear2006	0.01448	0.15744	0.09195	9.27.E-01	
fyear2007	-0.03520	0.18627	-0.18897	8.50.E-01	
fyear2008	0.28384	0.17730	1.60088	1.10.E-01	
fyear2009	-0.04553	0.17833	-0.25531	7.99.E-01	
fyear2010	0.05723	0.17158	0.33353	7.39.E-01	
fyear2011	0.22593	0.16961	1.33201	1.83.E-01	
fyear2012	-0.15911	0.18261	-0.87129	3.84.E-01	
fyear2013	0.12617	0.17459	0.72266	4.70.E-01	
fyear2014	-0.11867	0.17340	-0.68435	4.94.E-01	
fyear2016	-0.03885	0.16626	-0.23366	8.15.E-01	
fyear2017	-0.16826	0.19521	-0.86195	3.89.E-01	
fyear2018	0.11940	0.19632	0.60819	5.43.E-01	
fyear2019	0.21715	0.22891	0.94862	3.43.E-01	
fareaMaudaReef	-0.15345	0.12999	-1.18048	2.38.E-01	
fareaOffshore	-0.12171	0.14270	-0.85293	3.94.E-01	
fareaOnShore	-0.40754	0.08526	-4.77987	2.10.E-06	***
fareaShelfedge	0.14018	0.10953	1.27985	2.01.E-01	

Significances are *** < 0.001, ** < 0.01 and * < 0.05

Table 9. Year trends of probability sub-model

	Original		Converted		
Year	Mean	SE	Mean	Mean-SE	Mean+SE
1996	-1.8058	0.3634	0.1411	0.0485	0.2338
1997	-1.5477	0.3308	0.1754	0.0856	0.2652
1998	-1.6183	0.3320	0.1654	0.0766	0.2543
1999	-1.0852	0.3061	0.2525	0.1686	0.3364
2000	-2.6722	0.3705	0.0646	0.0007	0.1286
2001	-2.6570	0.3565	0.0656	0.0035	0.1277
2002	-3.3742	0.4368	0.0331	-0.0157	0.0819
2003	-2.2166	0.3375	0.0983	0.0247	0.1718
2005	-1.8678	0.3050	0.1338	0.0576	0.2100
2006	-1.0703	0.2931	0.2553	0.1752	0.3354
2007	-0.7220	0.3467	0.3269	0.2451	0.4088
2008	-0.8070	0.3293	0.3085	0.2265	0.3905
2009	-1.2434	0.3209	0.2238	0.1345	0.3131
2010	-1.0037	0.3172	0.2682	0.1828	0.3536
2011	-0.8127	0.3143	0.3073	0.2288	0.3858
2012	-1.4496	0.3298	0.1901	0.0992	0.2809
2013	-1.1257	0.3197	0.2450	0.1568	0.3331
2014	-1.2014	0.3187	0.2312	0.1427	0.3198
2016	-0.6372	0.3115	0.3459	0.2772	0.4145
2017	-1.8352	0.3499	0.1376	0.0492	0.2260
2018	-1.8665	0.3531	0.1339	0.0457	0.2222
2019	-2.5254	0.3899	0.0741	0.0011	0.1470

Table 10. Year trends of positive catch sub-model

	Original		Converted		
Year	Mean	SE	Mean	Mean-SE	Mean+SE
1996	3.1228	0.1649	2.2710	1.1012	3.4407
1997	2.9238	0.1377	1.8611	1.1120	2.6102
1998	3.0249	0.1395	2.0591	1.1903	2.9280
1999	3.1855	0.1186	2.4179	1.5041	3.3317
2000	3.2332	0.1808	2.5362	1.0535	4.0188
2001	2.7114	0.1697	1.5050	0.8124	2.1976
2002	3.1707	0.2357	2.3823	0.6018	4.1628
2003	3.2991	0.1491	2.7087	1.3764	4.0410
2005	3.1397	0.1159	2.3096	1.4692	3.1501
2006	3.1369	0.1012	2.3032	1.5718	3.0345
2007	3.0774	0.1425	2.1703	1.2188	3.1218
2008	3.3987	0.1298	2.9925	1.6724	4.3126
2009	3.0763	0.1308	2.1678	1.2953	3.0403
2010	3.1621	0.1203	2.3620	1.4636	3.2605
2011	3.3427	0.1190	2.8296	1.7042	3.9551
2012	2.9641	0.1335	1.9378	1.1712	2.7044
2013	3.2422	0.1240	2.5589	1.5300	3.5879
2014	3.0039	0.1232	2.0163	1.2702	2.7624
2016	3.0786	0.1144	2.1729	1.4074	2.9384
2017	2.9425	0.1541	1.8963	1.0366	2.7560
2018	3.2309	0.1543	2.5302	1.2691	3.7914
2019	3.3194	0.1894	2.7644	1.0269	4.5020

Table 11. Point estimates of Grid-type Trolling Index

Year	Prob*Pos	Standardized
1996	0.3205	0.7239
1997	0.3265	0.7373
1998	0.3407	0.7693
1999	0.6105	1.3788
2000	0.1639	0.3702
2001	0.0987	0.2228
2002	0.0789	0.1781
2003	0.2662	0.6011
2005	0.3090	0.6979
2006	0.5881	1.3281
2007	0.7096	1.6024
2008	0.9233	2.0850
2009	0.4852	1.0958
2010	0.6335	1.4307
2011	0.8696	1.9638
2012	0.3683	0.8317
2013	0.6268	1.4156
2014	0.4662	1.0529
2016	0.7516	1.6973
2017	0.2610	0.5893
2018	0.3389	0.7654
2019	0.2048	0.4626

Table 12. Grid-type Trolling index with confidence intervals calculated by 1000 times bootstrap

year	5 percentile	25 percentile	Median	75 percentile	95 pecentile
1996	0.407	0.580	0.718	0.884	1.145
1997	0.518	0.635	0.734	0.828	0.998
1998	0.525	0.659	0.772	0.877	1.047
1999	1.029	1.205	1.364	1.520	1.803
2000	0.197	0.290	0.365	0.444	0.576
2001	0.138	0.184	0.217	0.254	0.310
2002	0.075	0.127	0.171	0.225	0.330
2003	0.390	0.500	0.591	0.690	0.838
2004					
2005	0.527	0.618	0.692	0.776	0.875
2006	1.101	1.233	1.321	1.421	1.575
2007	1.116	1.376	1.581	1.776	2.068
2008	1.552	1.840	2.071	2.294	2.699
2009	0.784	0.949	1.084	1.213	1.425
2010	1.096	1.273	1.421	1.567	1.783
2011	1.529	1.771	1.968	2.162	2.425
2012	0.596	0.731	0.824	0.925	1.091
2013	1.045	1.257	1.392	1.541	1.793
2014	0.819	0.946	1.045	1.148	1.306
2015					
2016	1.348	1.559	1.691	1.839	2.057
2017	0.403	0.495	0.577	0.668	0.790
2018	0.482	0.636	0.753	0.886	1.092
2019	0.255	0.369	0.465	0.564	0.731

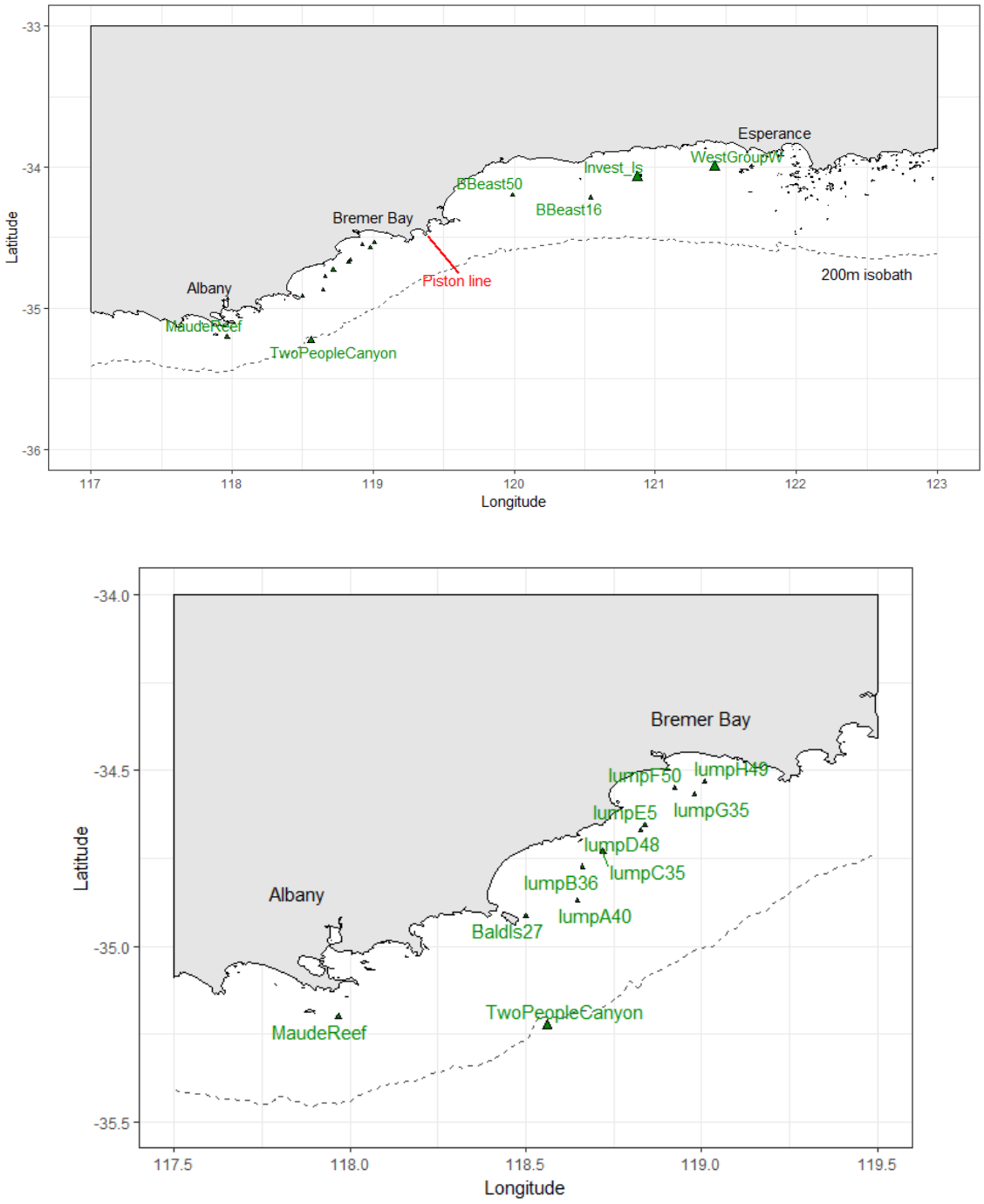

Fig. 1. Map and relating places.

Lower panel is an enlargement of a part of upper panel. Size in the cross mark reflects a determined range of effect of the lump.

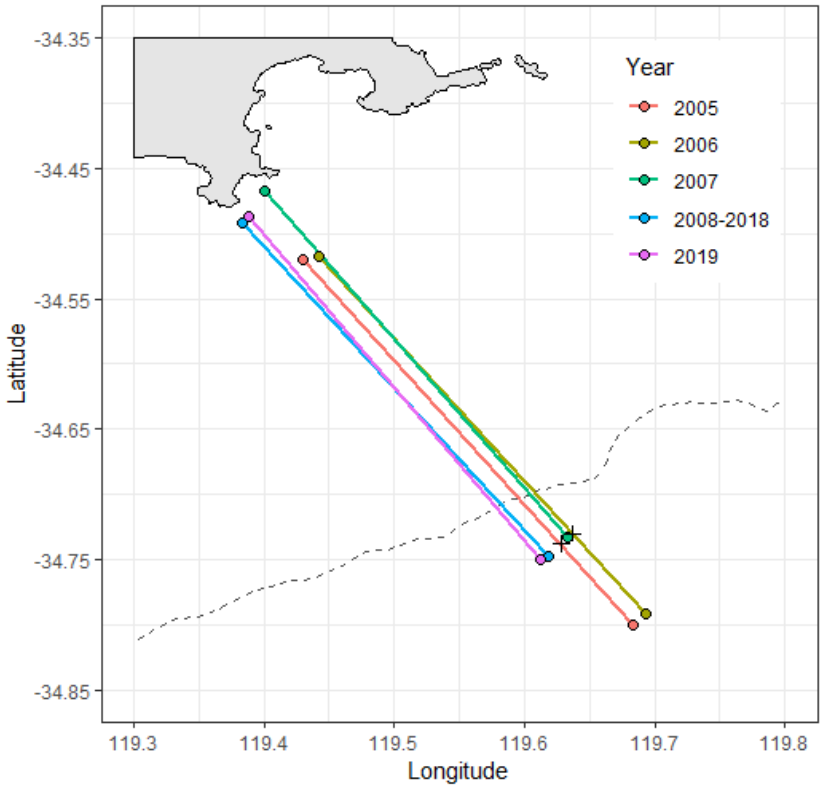

Fig. 2. Locations of piston-line.

Circles denote each end of piston-line surveyed. Cross marks are the offshore point of the 2005 and 2006 piston lines that adjusted to the 2007 piston-line.

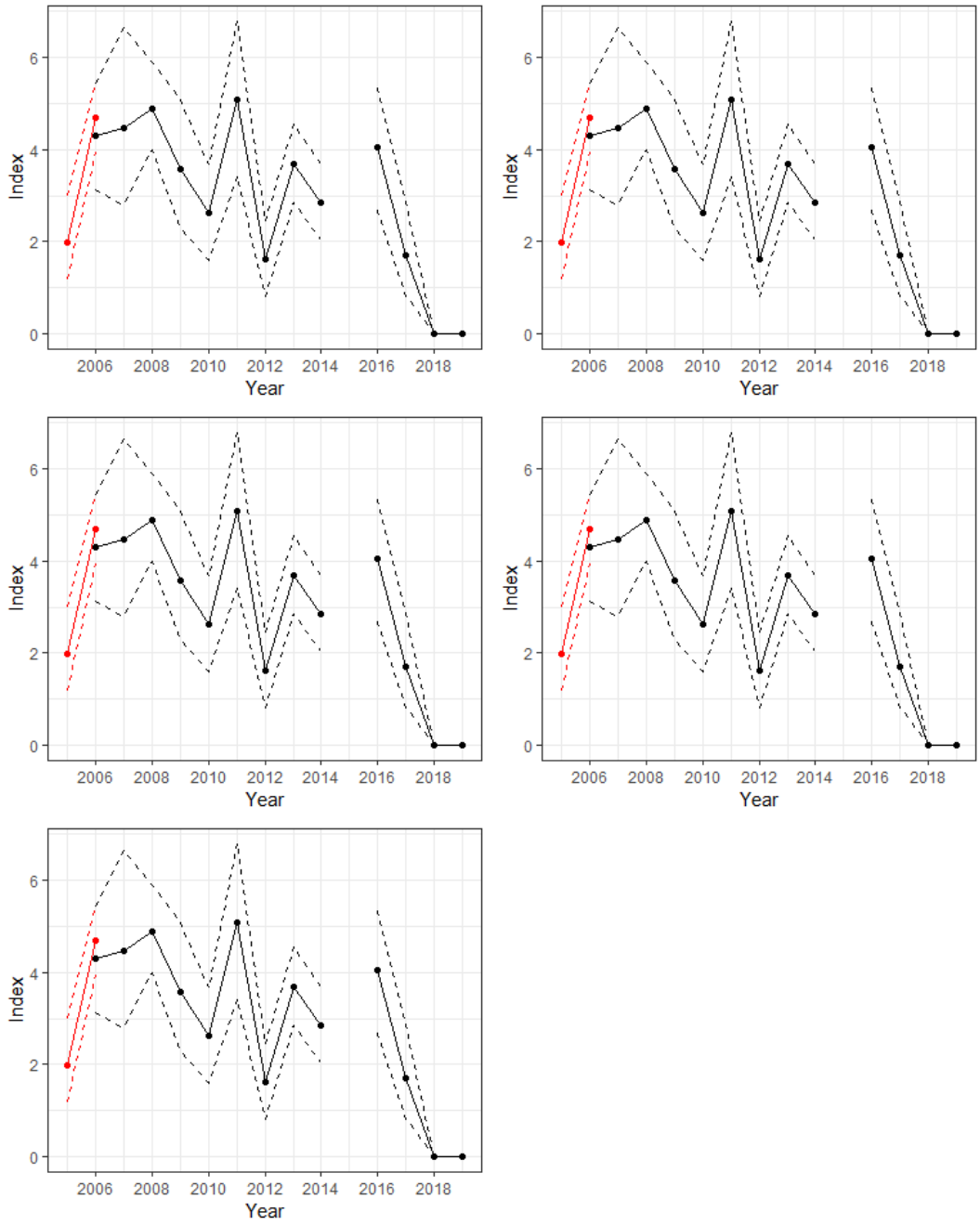

Fig. 3. Five types of the piston-line trolling index by different school/catch definition.

Showing median, 5 and 95 percentiles. Red lines and points were the data from the acoustic survey and Black lines and points were the data from the trolling survey.

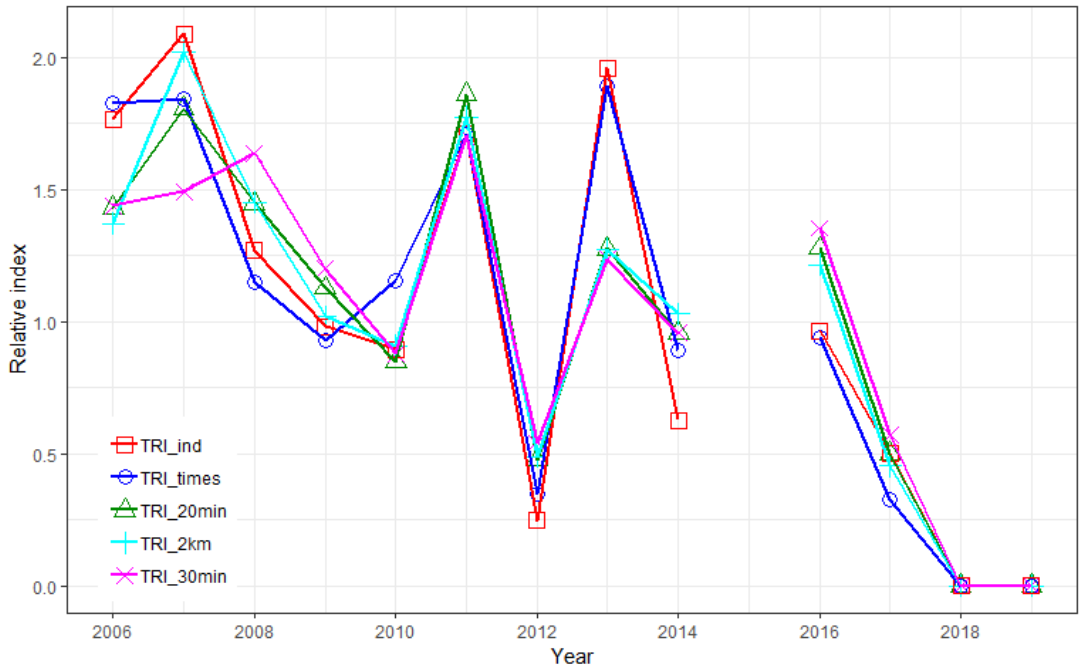

Fig. 4. Comparison of the median from five types of piston-line trolling index by different school/catch definition.

Standardized with the mean of each index. Only shows that from the trolling survey.

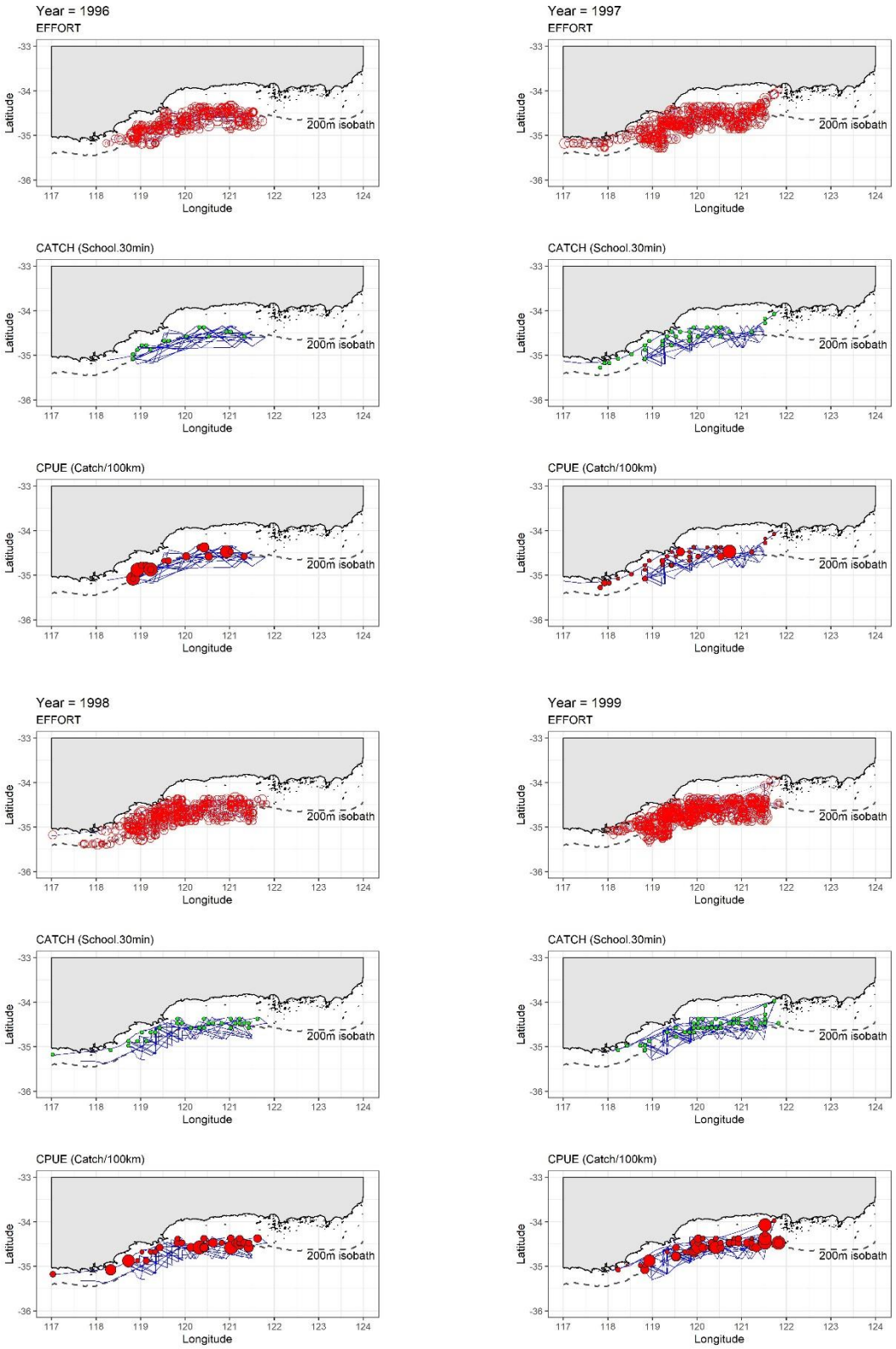

Fig. 5. Distributions of effort, age-1 SBT catch and CPUE by year

Blue line is the trajectory of the vessel while trolling. Some points of anomalously high CPUE with little effort were not shown.

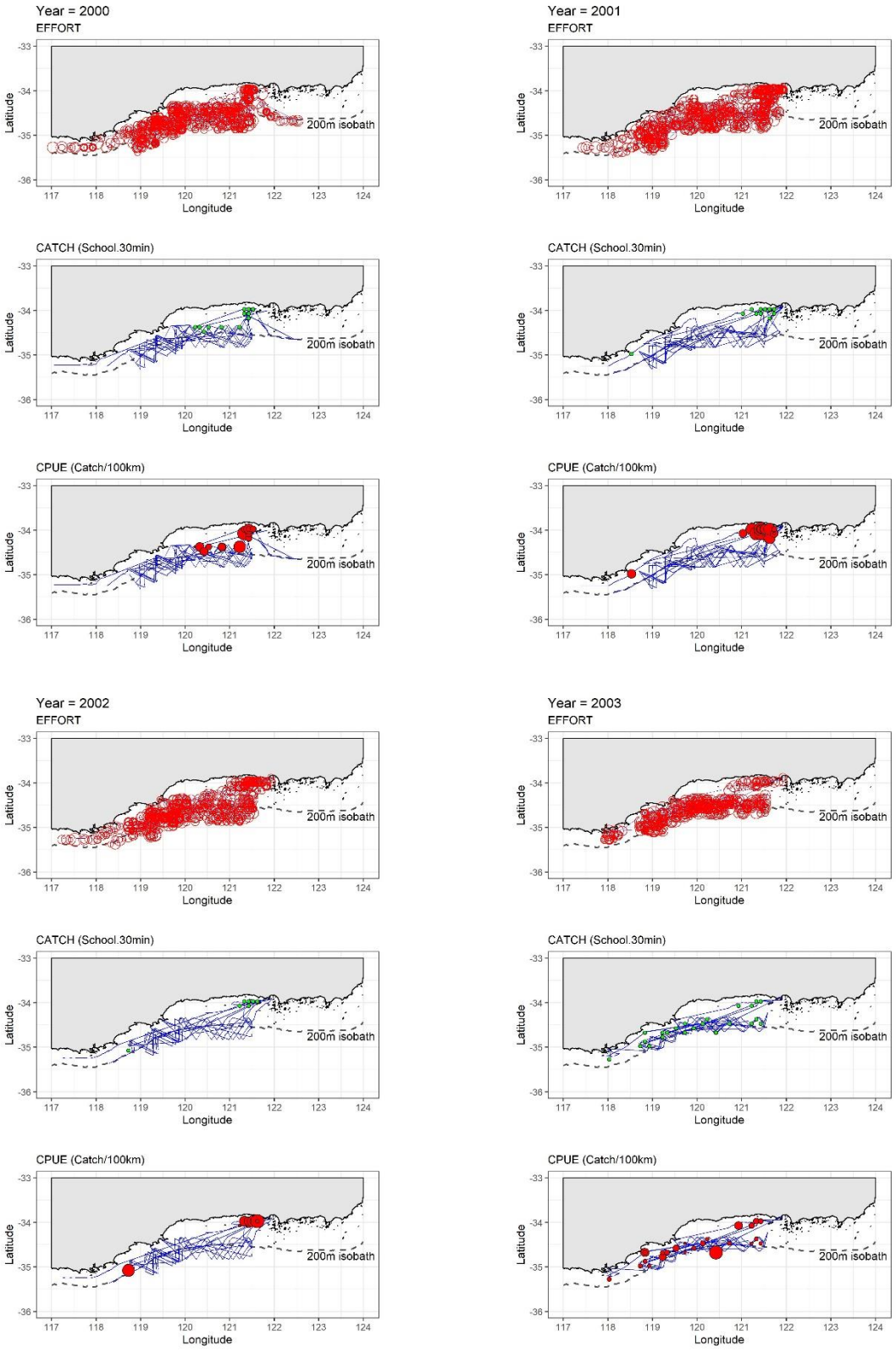
Year = 2000
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2001
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2002
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2003
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Latitude
Longitude
200m isobath

Fig. 5. (cont'd)

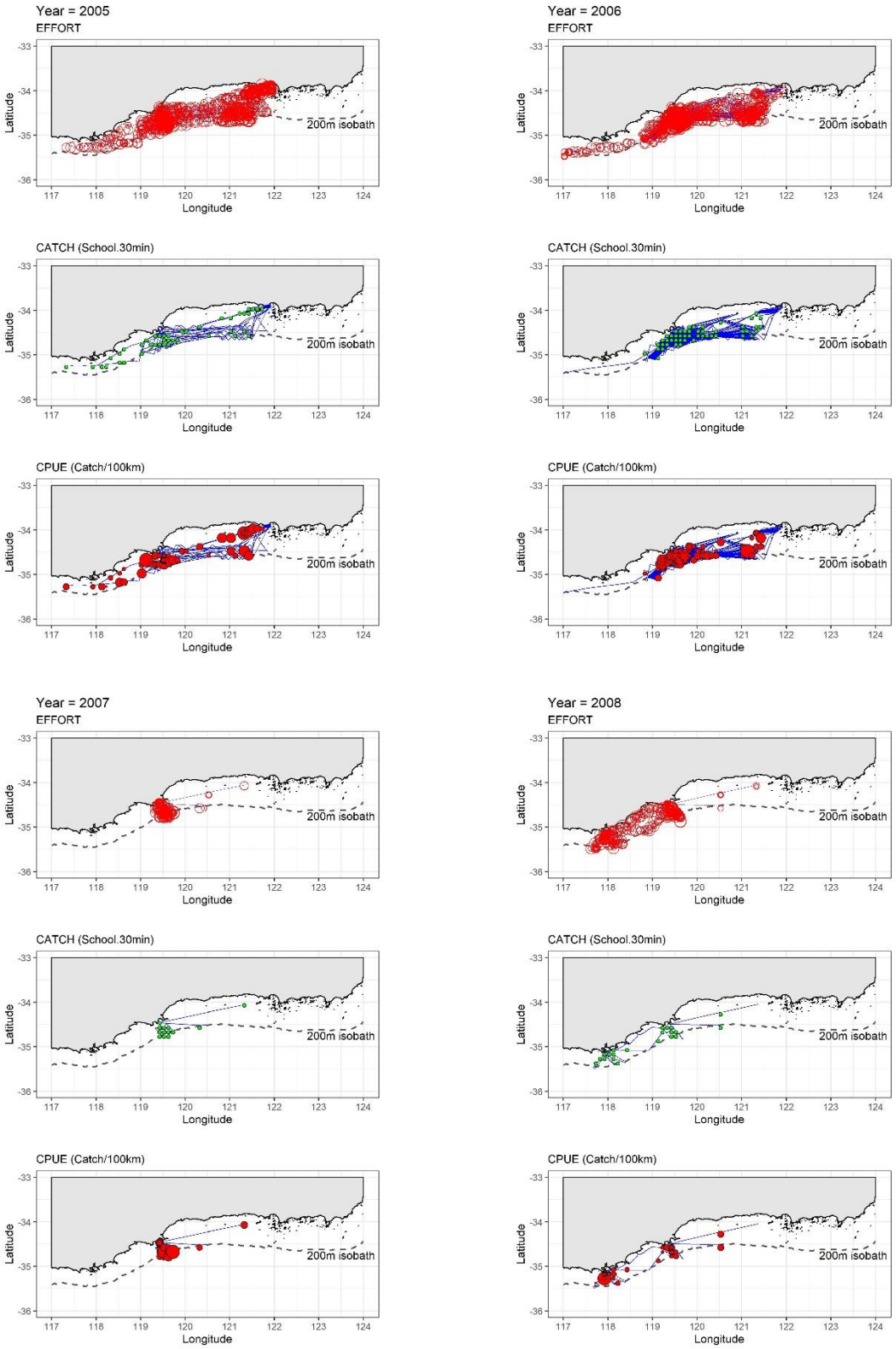
Year = 2005
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2006
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2007
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2008
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
200m isobath
Latitude
Longitude
-33
-34
-35
-36
117
118
119
120
121
122
123
124

Fig. 5. (cont'd)

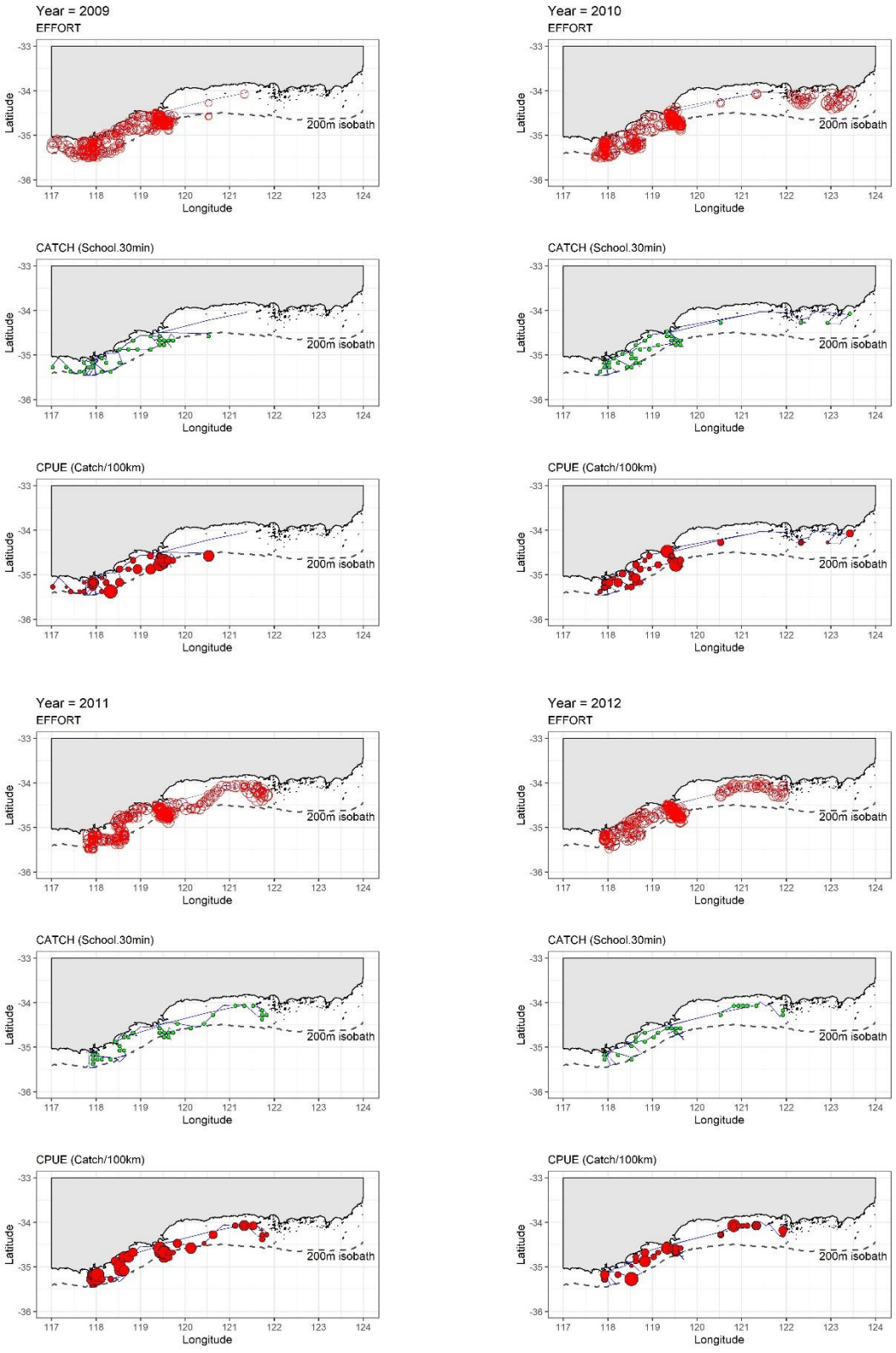
Year = 2009
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2010
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2011
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2012
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Latitude
Longitude
200m isobath

Fig. 5. (cont'd)

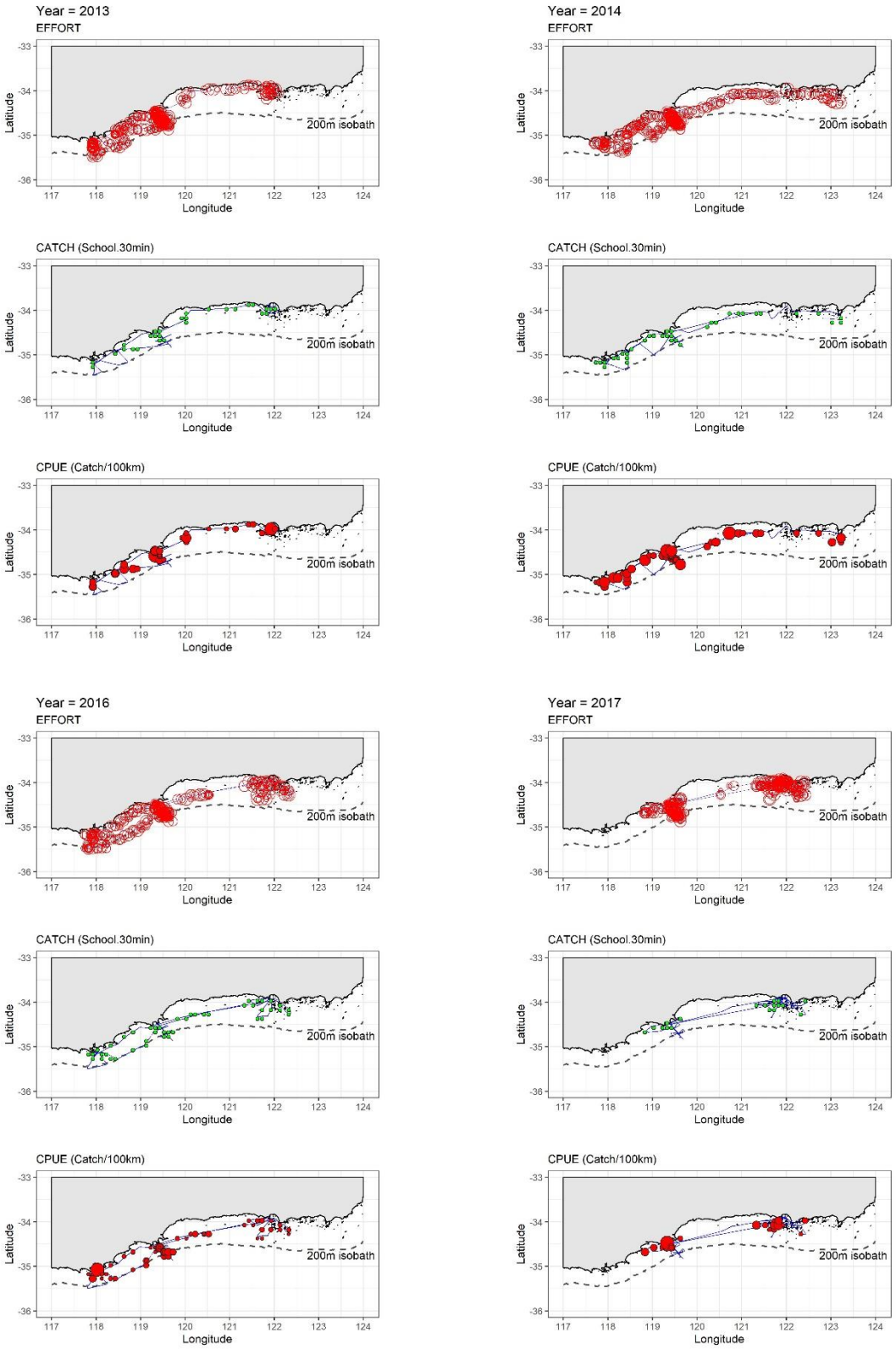
Year = 2013
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2014
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2016
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2017
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Latitude
Longitude
200m isobath

Fig. 5. (cont'd)

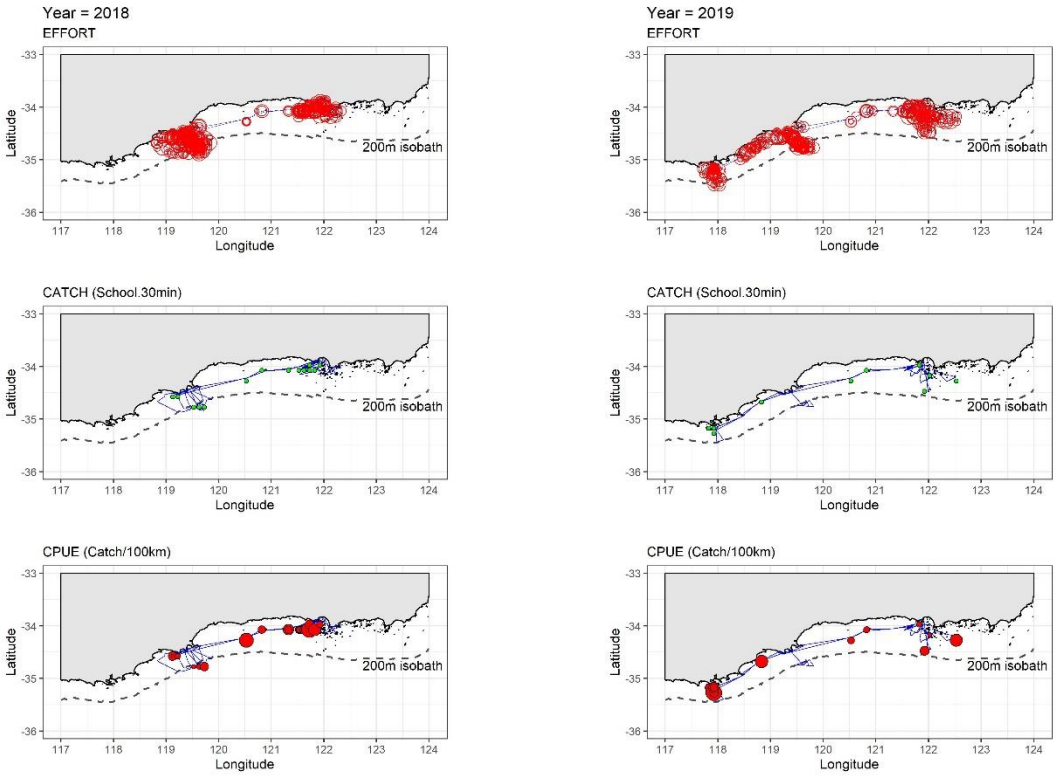
Year = 2018
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Year = 2019
EFFORT
CATCH (School.30min)
CPUE (Catch/100km)
Latitude
Longitude
200m isobath
-33
-34
-35
-36
117
118
119
120
121
122
123
124

Fig. 5. (cont'd)

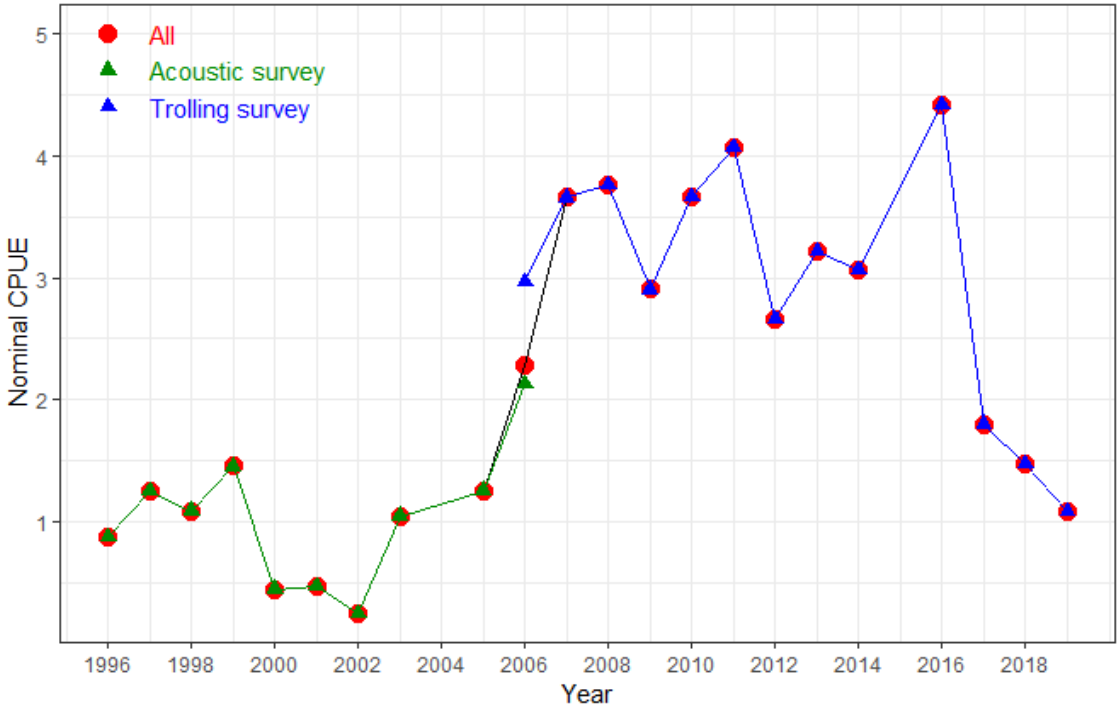

Fig. 6. Nominal CPUE of TRG.

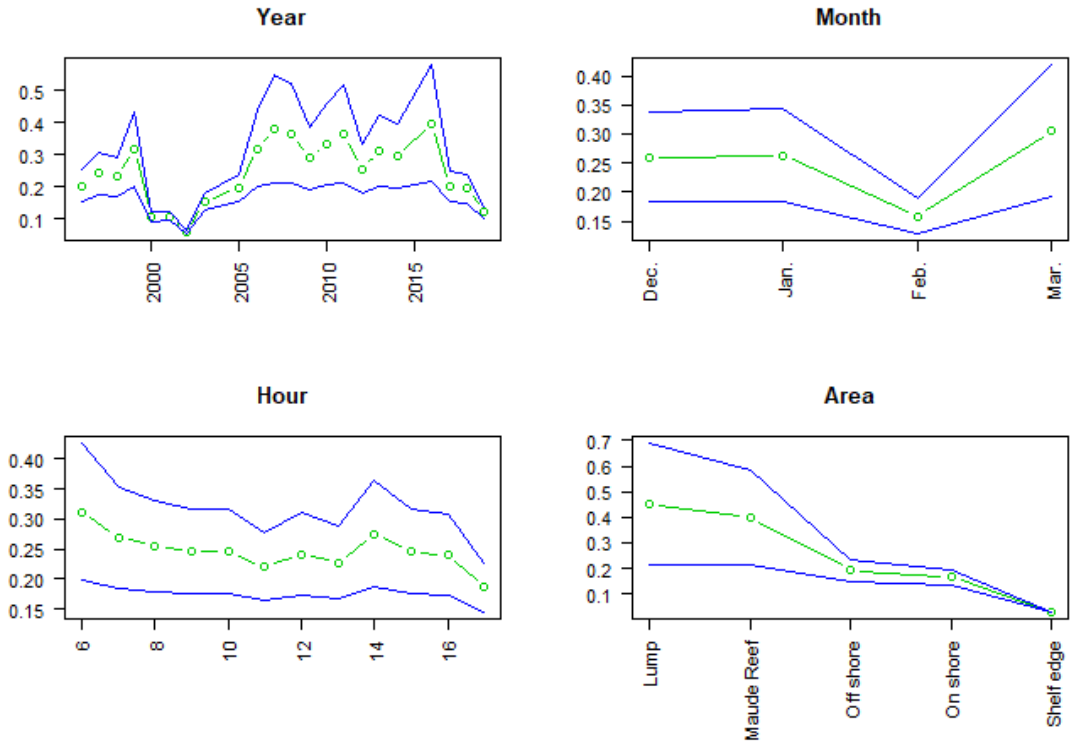

Fig. 7. Probability of catch for variables that were selected by AIC.

Green is mean and blue is mean+SD. Catch was defined as schools with a definition of 30 minutes is necessary for a different school.

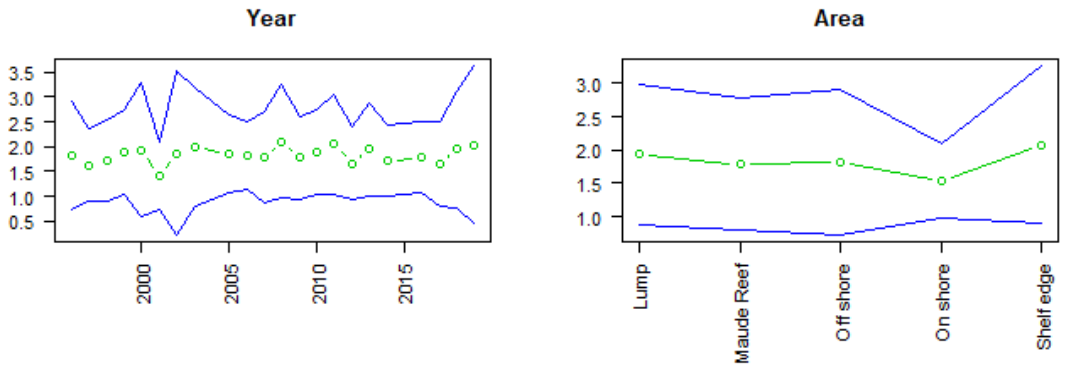

Fig. 8. Catch in positive catch for variables that were selected by AIC.

Green is mean and blue is mean+SD. Catch was defined as school with definition of 30 minutes is necessary for different school.

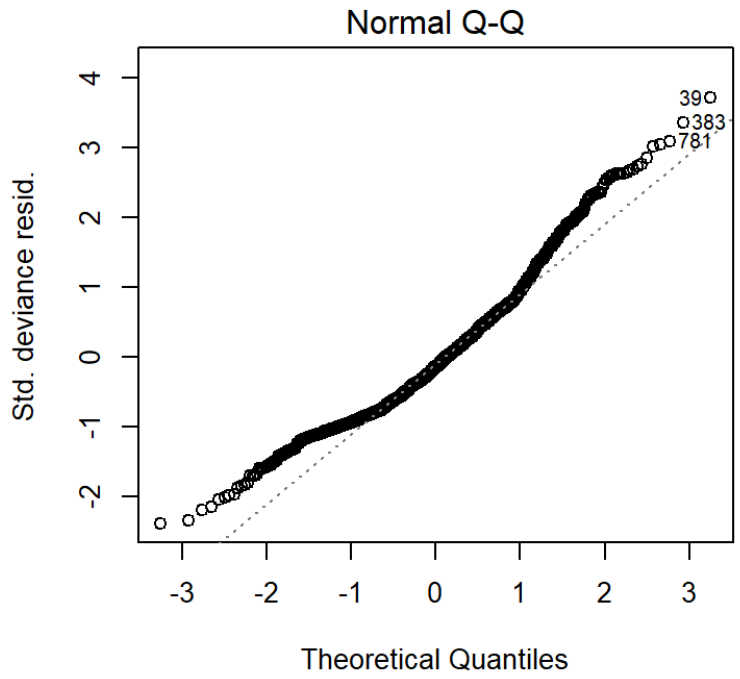

Fig. 9. QQ plot of GLM for positive catch sub-model.

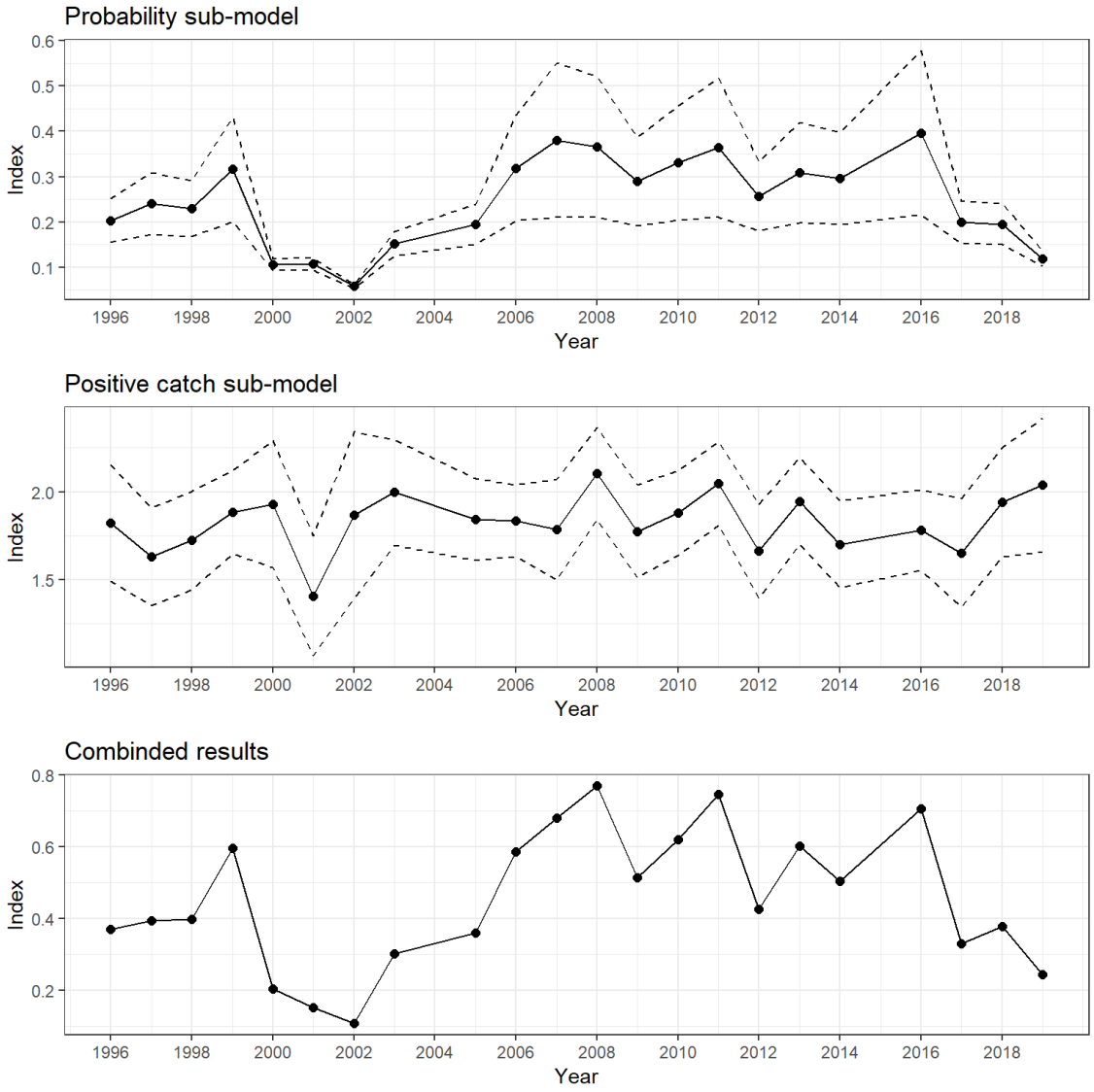

Fig. 10. The probability sub-model, the positive catch sub-model, and combined index from two sub-model (point estimation standardized TRG).

Upper panel shows the year trend from the probability sub-model. Mean+1SD. The middle panel shows the year trend form the positive catch sub-model. Mean+1SD. Lower panel shows TRG which is a product of two sub-models.

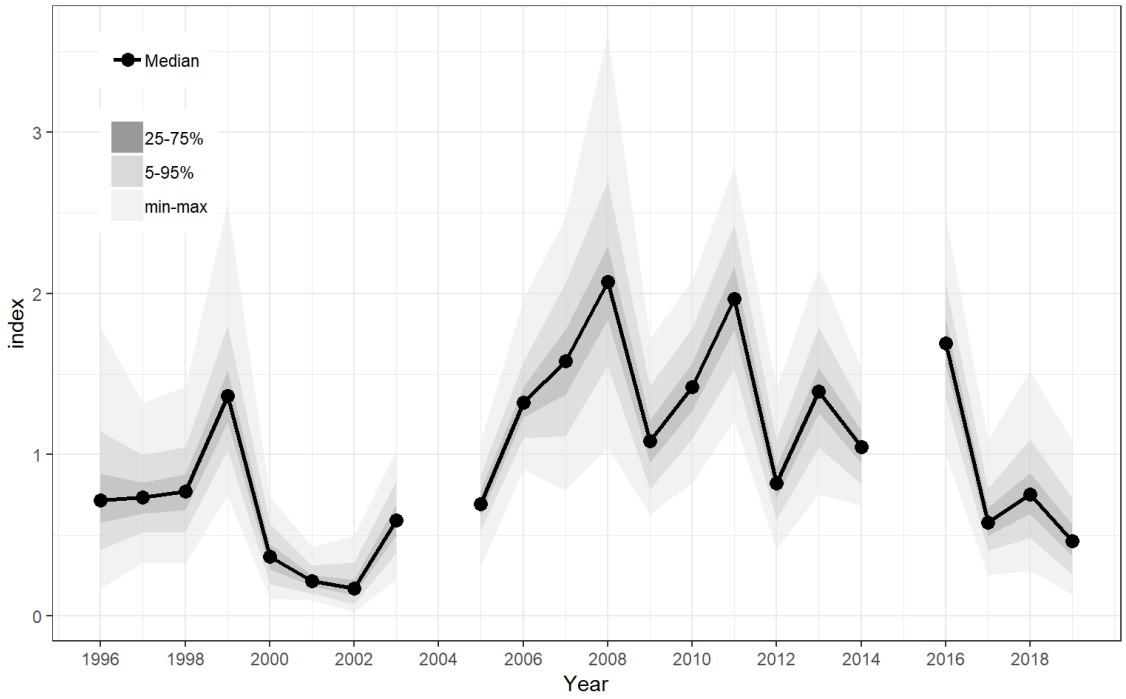

Fig. 11. TRG with confidence intervals.

Estimate was simulated with 1000 times bootstrapping.

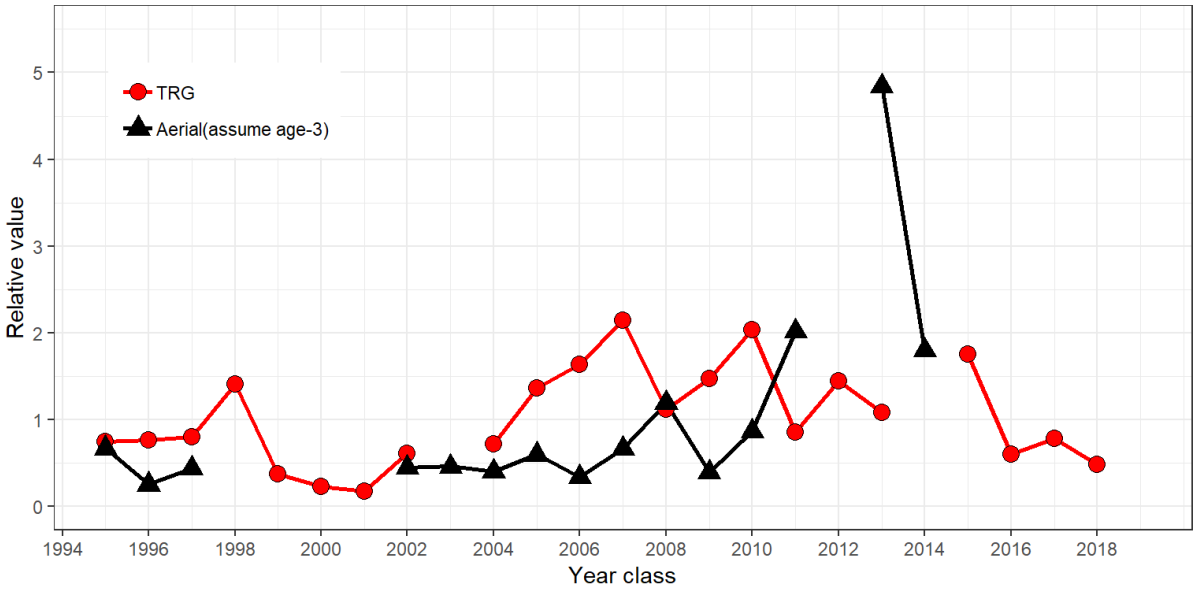

Fig. 12. Comparison between aerial survey index and TRG by year class (cohort).
Assigned year class for aerial survey assuming age-3 fish observed.

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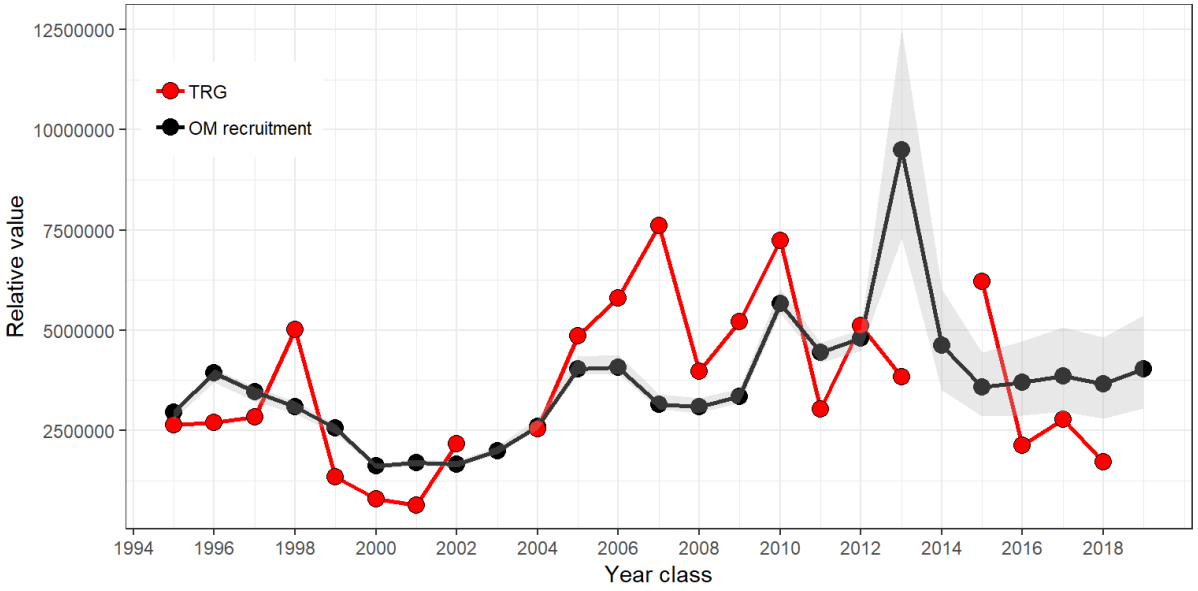

Fig. 13. Comparison between OM recruitment from the 2017 stock assessment and TRG by year class (cohort).
Range of OM recruitment is 25-75 percentiles.

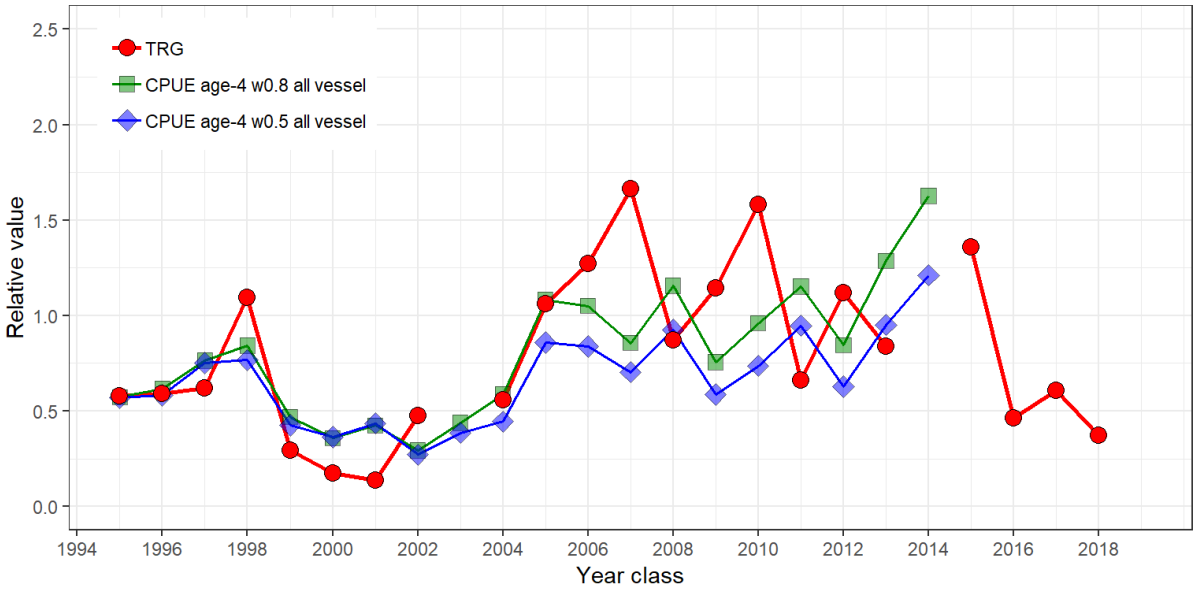

Fig. 14. Comparison between the age-4 all vessel CPUE (w0.5 and w0.8) of Japanese longline and TRG by year class (cohort).

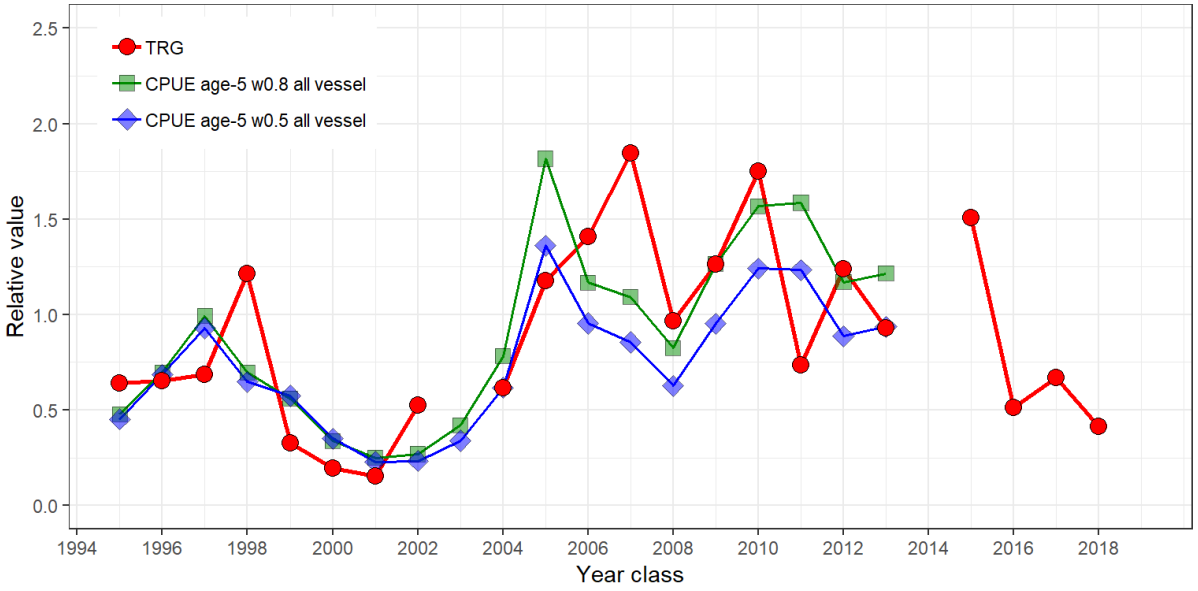

Fig. 15. Comparison between the age-5 all vessel CPUE (w0.5 and w0.8) of Japanese longline and TRG by year class (cohort).